Direct Photons in PHENIX at RHIC

E Kistenev[1] (for the PHENIX Collaboration[2])

[1] Physics Department, 510c, Brookhaven National Laboratory, Upton, NY 11973-5000, USA

E-mail: kistenev@bnl.gov

Abstract.

PHENIX results on direct photon production in p+p, d+Au, Cu+Cu and Au+Au collisions are presented. Direct photon yield at high $p_{\rm T}$ is consistent with the dominance of the LO processes (inverse compton scattering and quark-antiquark annihilation). In heavy ion collisions the low $p_{\rm T}$ direct photons exhibit an order of magnitude exponential shape enhancement consistent with thermal emission from QGP. The thermal nature of this enhancement is further confirmed by large elliptic flow of direct photons below $p_{\rm T}\sim 5GeV/c$.

1. Introduction

Among the observables used to probe the high temperature and high density phase of heavy nucleus collisions direct photons are considered of particular interest. Nuclear modifications to the yield of direct photons reflects medium effects on contributing production mechanisms. Hard scattered photons produced early in collision history are not expected to flow. The rate and azimuthal asymmetries of photons produced at low to medium $p_{\rm T}$ (1-5GeV/c) [1, 2] will be influenced by the emission from expanding medium and reflect initial anisotropy of the collision region.

2. Direct photon measurements

The data presented in this paper are from p+p , d+Au , Cu+Cu and Au+Au data sets at $\sqrt{s_{NN}}$=200 GeV taken with the PHENIX detector [3] in 2004-2008. The PHENIX central arms, each covering ± 0.35 units of pseudorapidity around midrapidity and 90° in azimuth, contain charged-particle tracking chambers and two kinds of electromagnetic calorimeters. The BBC and Zero-Degree Calorimeters (ZDC) were used for minimum bias event selection and centrality determination (when appropriate).

Direct photons yields, their flow and gamma-jet correlations are measured by statistical subtraction of the estimated meson (mainly π^0) decay photon contribution from the inclusive photon and γ-h samples. An alternative method for measuring direct photons is provided by the low-mass lepton e^+e^- pairs produced by a higher order QED correction to the real photon emission process. Any source of real photons must also

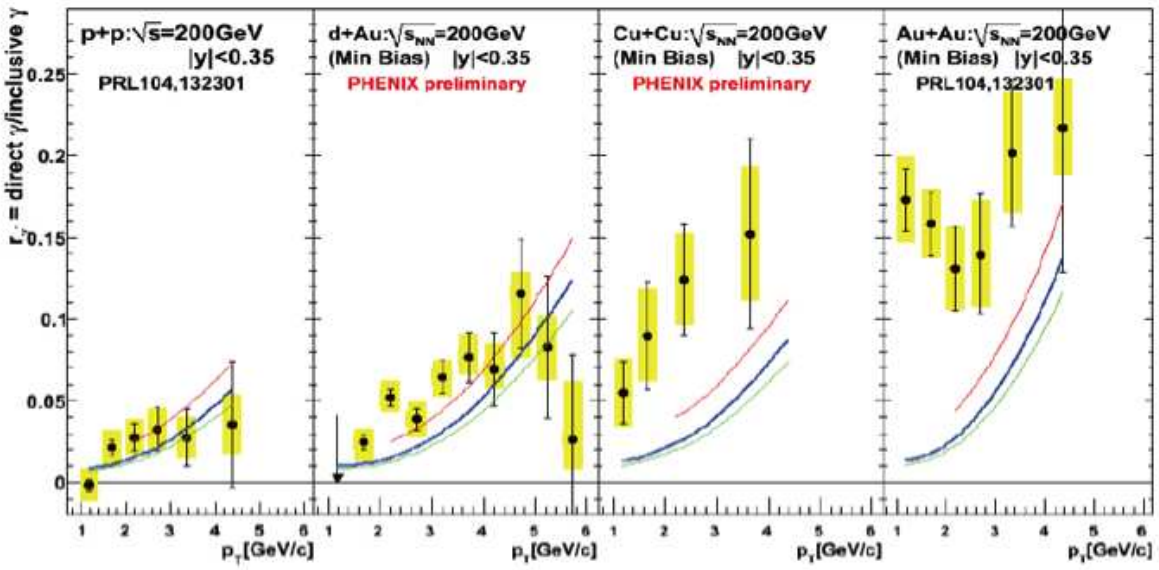

Figure 1. (color online) The fraction r_γ of direct photons in the inclusive photon yield as a function of $p_{\rm T}$ in p+p , d+Au , Cu+Cu and Au+Au (min. bias) collisions [1]. The error bars and the boxes represent statistical and systematic uncertainties, respectively. The curves are from an NLO pQCD calculation.

emit virtual photons and their yield is related to that of real photons. In the low mass region, where the $p_{\rm T}$ of the e^+e^- pair is much greater than its mass ($m_{ee} \ll p_T$), the yield of the intermediate virtual photons is approximately the same as that of real photons. Therefore, in this quasi-real virtual photon region, the production of real direct photons can be deduced from measurements of e^+e^- pairs.

Figure 1 shows the fraction $r_\gamma = \frac{direct\,\gamma}{inclusive\,\gamma}$ of the direct photon component in p+p , d+Au , Cu+Cu and Au+Au collisions, respectively. The curves represent the expectations from a NLO pQCD calculation [4]. The three curves correspond (from top to bottom) to the theoretical scales set to $\mu = 0.5\ p_T$, p_T, and $2\ p_T$, respectively. While the fraction r_γ is consistent with the NLO pQCD calculation in p+p and d+Au, it is larger than the calculation in both Cu+Cu and Au+Au for $p_T < 5$ GeV/c.

In Figure 2 the direct photon yield in Au+Au computed using the relation $dN_\gamma^{dir}(p_{\rm T}) = r_\gamma \times dN_\gamma^{incl}(p_T)$ is compared in to the direct photon data from [5, 6] and NLO pQCD calculations. In central collisions it shows excess over collision scaled p+p data, and the shape of the excess is well described by the exponential with inverse slope $T \simeq$ 220 MeV. If the direct photons in Au+Au collisions are of thermal origin, the inverse slope T is related to the initial temperature T_{init} of the dense matter. In hydrodynamical models, T_{init} is 1.5 to 3 times T due to the space-time evolution [7].

If photons are radiated inside an expanding matter having azimuthally anisotropic momentum distribution, their momenta add or subtract for radiation along or opposite to the motion. Neglecting pion mass, thermal photons must have the same or greater

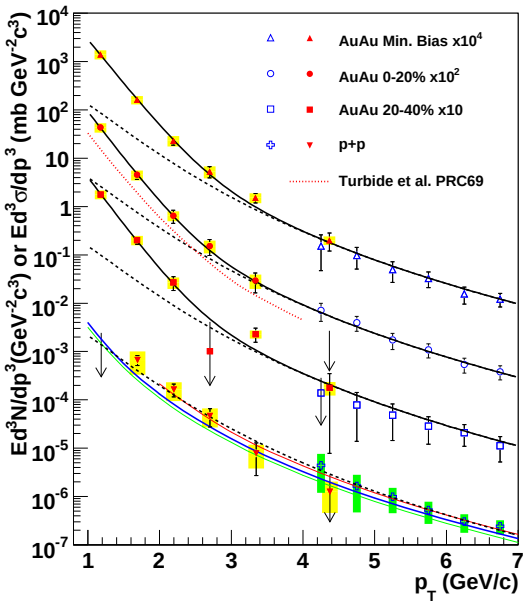

Figure 2. (color online) Invariant cross section p+p and invariant yield Au+Au of direct photons as a function of p_T [1, 5, 6]. The solid curves on the p+p data represent NLO pQCD direct photon calculations [4]. The dashed curves on the Au+Au data show the p+p fit scaled by $T_{\rm AA}$. The solid curves on the Au+Au data are an exponential fit plus the $T_{\rm AA}$ scaled p+p fit.

elliptic flow (v_2) as pions [8].

An earlier low $p_{\rm T}$ measurements of photon flow for π^0 and inclusive photons has been published in [9]. Using recent (2007) high statistics p+p and Au+Au data PHENIX extended $p_{\rm T}$ range for v_2 measurements to 15 GeV/c and dramatically improved v_2 precision in the low to medium $p_{\rm T}$ range.

To correct for a large contribution from hadron decays, predominantly from π^0 (80%) and η (15%), and for cluster merging for high $p_{\rm T}$ π^0's the v_2 flow of the direct photons was calculated as $v_2^{\gamma,dir} = \frac{R_\gamma(p_T)\times v_2^{\gamma,inc} - v_2^{\gamma,bg}}{R_\gamma(p_T)-1}$, where $R_\gamma(p_T) = N^{inc}(p_T)/N^{bg}(p_T)$ is the direct photon excess ratio, and $N^{inc} = N^{meas} - N^{hadr}$ is for inclusive photons. The v_2 values for π^0 in minimum bias Au+Au events are compared to similar data for inclusive photons in Figure 3 left panel [2]. The v_2 data for direct photons in the most central Au+Au events are shown in the right panel in the same Figure.

The two sets of points (inclusive photons and π^0) are barely different in the thermal $p_{\rm T}$ range indicating the dominance of the photons with flow values close to that of hadrons. Qualitative conclusions of the left panel are confirmed quantitatively in the right panel displaying subtraction data for direct photons in the most central Au+Au collisions. Below $p_T \sim 5GeV/c$ v_2 of direct photons has value comparable to that of hadrons. At higher $p_{\rm T}$ it drops to zero as expected if photons produced in hard scattering (reverse compton scattering and quark-antiquark annihilation) dominate in

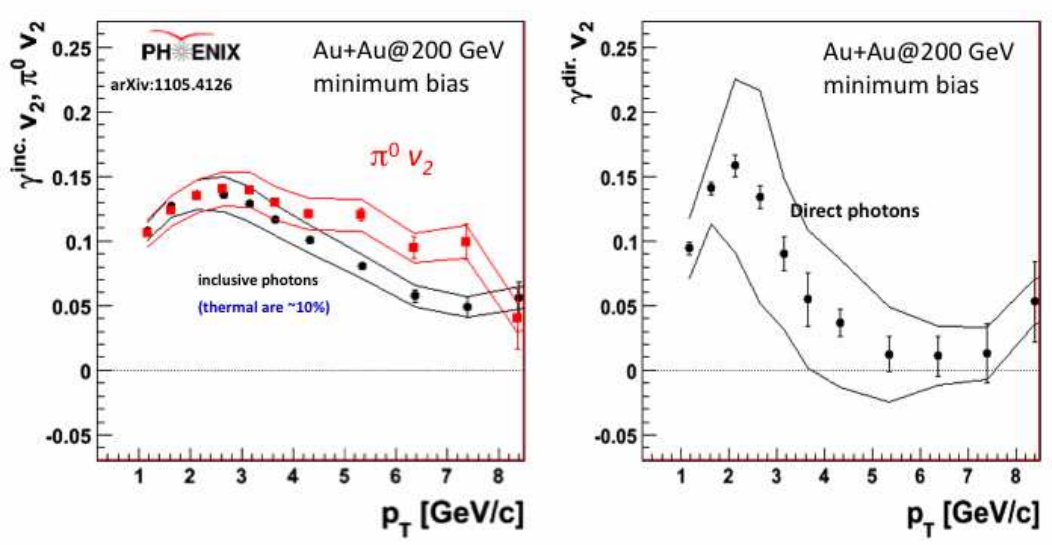

Figure 3. (color online) Left panel: Comparison between elliptic flow (v_2) of π^0 and inclusive photons in minimum bias Au+Au collisions. Right panel: Direct photon flow in the most central Au+Au collision computed using a subtraction procedure.

that $p_{\rm T}$ range.

3. Summary

The direct photon production data accumulated by PHENIX confirm the unique role of direct photons in probing the sQGP evolution and its properties. Consistency between high $p_{\rm T}$ yields of direct photons in heavy ion collisions and collision scaled p+p yield confirms collision scaling. The low $p_{\rm T}$ behavior of direct photons in central Au+Au collisions is dramatically different from all other particles exhibiting an order of magnitude exponential enhancement as $p_T \rightarrow 0$ suggestive of thermal emission from the sQGP. The assumed thermal nature of low to medium $p_{\rm T}$ photons is further confirmed by the presense of a large flow of direct photons in $p_{\rm T}$ range below 5 GeV/c.

References

[1] A.Adare et al., Phys. Rev. C81, 034911 (2010)
[2] arXiv:1105.4126v1 [nucl-ex] 20 May 2011
[3] K.Adcox et al. (PHENIX), Nucl. Instrum. Meth., **A499** 469 (2003)
[4] L. E. Gordon and W. Vogelsang, Phys. Rev. D **48**, 3136 (1993) and W. Vogelsang, private communication (2008).
[5] S.S. Adler *et al.*, Phys. Rev. Lett. **94**, 232301 (2005).
[6] S.S. Adler *et al.*, Phys. Rev. Lett. **98**, 012002 (2007).
[7] D. d'Enterria and D. Peressounko, Eur. Phy. J. **C46**, 451 (2006).
[8] B.Kopeliovich, Private communicaion (May 2011)
[9] S.Adler et al., Phys. Rev. Lett. 96, 032302 (2006)